

Post-fire habitat restoration of sables during winter season in northern slope of the Great Xing'an Mountains

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Abstract: Habitat loss and fragmentation have been associated with the decline of endangered species. In 1987, a catastrophic fire in the northern Great Xing'an Mountains of China, where the main habitat of sables (*Martes zibellina*) is located, aggravated the loss and fragmentation of the forest landscape. Due to restricted distribution and low population density, sables were listed in the national first-grade protected species in China. The objective of this paper was to identify to what extent the habitat of sables had been restored 13 years after the fire. Based on the behavioral data, which came from field survey information by radio-tracking, GPS (Global Positioning System) and forest inventory data, suitability habitat maps were derived using the Ecological Niche Suitability Model (ENSM). In addition, the habitat structure was analyzed with selected landscape indices. Although forest cover mostly had been restored by 2000, the results indicated that, compared to the pre-fire situation, the areas of suitable habitat had been reduced significantly, especially those of less suitable, marginally suitable and moderately suitable designation. Fragmentation was aggravated, and suitable patches were found to be further isolated with the exception of those in most suitable areas. The ratio of the patch perimeter to area in unsuitable, moderately suitable and suitable areas decreased, while the ratios within other suitability types increased. Moreover, the percentage of soft boundaries decreased slightly, which can influence the redistribution of sables. The results above indicated that the suitable habitat had deteriorated, and the restoration of the sables' habitat remained to be done.

Keywords: Suitable habitat; Habitat loss; Fragmentation; Edge effect; Habitat restoration.

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Introduction

Habitat fragmentation, the process of subdividing a continuous habitat into smaller sections, occurs under natural factors such as fire, windfall and human disturbance (Wright 1974; Pickett and Thompson 1978; Foster 1980), mainly of expansion and intensification of human land use (Burgess and Sharp 1981). Such fragmentation was traditionally considered in three major aspects, including loss of the original habitat, reduction in habitat patch size and increasing isolation of habitat patches (Andrén 1994). All of these aspects contributed to the decline of bio-diversity and changes in species distribution. Habitat fragmentation subsequently resulted in intensive changes of abiotic and biotic factors in patch edges, called edge effects (Wright 1974; Lovejoy *et al.* 1986; Malcom 1994; Collinge and Palmer 2002; Laurance *et al.* 2002; Desrochers *et al.* 2003), which further reduced the core area of suitable habitat and accelerated the invasion of exterior species (Wu and Li 2003). Recently, many ecologists have been inclined to differentiate the ecological effects of habitat loss and habitat fragmentation (Fahrig 1997; Flather and Bevers 2002; McGarigal and Cushman 2002). Therefore, habitat loss, habitat fragmentation and prevalence of habitat edge should be key for the declines of bio-diversity and changes of distribution.

The catastrophic fire of 1987 that occurred in the northern

Great Xing'an Mountains not only burned out more than 1.33×10^6 hm² of natural forest, but also produced a strikingly heterogeneous mosaic of various burn severities and islands of unburned vegetation across the landscape (Kong *et al.* 2003); and this inevitably resulted in both severe habitat loss and fragmentation of wildlife. The effects were especially serious for many rare animals like sables (*Martes zibellina*), threatening their survival and distribution. Post-fire forest landscape restoration had been a chief research concern in this area, and lots of studies on forest restoration have been conducted at species, community and landscape scales (Guan and Zhang 1990; Wen and Zheng 1996; Yang *et al.* 1998; Luo 2002; Kong *et al.* 2004). However, few studies had focused on the restoration of wildlife habitat, particularly at the landscape scale (Zhuang and Chen 1989). Sables were chosen for this study because, with restricted distribution and low population density, they were especially sensitive to habitat change. Previous studies based on intensive field surveys provided useful information for the identification of suitable habitat for sables (Zhang and Ma 1999; Zhang and Ma 2000 a, b). Since ecological factors change with seasons and winters are both long and extremely cold in this area, research on habitat restoration was conducted during winter.

The aim of this paper was to identify to what extent the suitable habitat of sables had been restored after fire, with the pre-fire situation being a reference point. Ecological factors affecting sables during winter, identified in field surveys reported in existing literature, were combined with forest inventory data (forest stand maps). These yielded suitable habitat maps, derived for both pre-fire (1987) and post-fire (2000) stages. We subsequently calculated landscape indices describing suitable habitat loss, habitat fragmentation and changes of habitat edge to identify changes of suitable habitat structure in both pre-fire and

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post-fire stages, and analyzed influences of the habitat change on the distribution of sables.

Study area and methods

Study area

This study was conducted in the Tuqiang Forest Bureau located in the northern Great Xing'an Mountains (Fig. 1), which was one of four forest bureaus burned in the 1987 fire. Geographic coordinates for this area are 122°18'05"E–123°29'00"E, and 52°15'55"N–53°33'40"N. The area whose average altitude is about 500 m, is marked by gentle undulating hills and open river

valleys. And it experiences long, cold winters, and short, hot summers. The mean annual temperature is -4.94°C , with the lowest temperature at about -53°C . Mean annual precipitation is 432mm with relatively dry springs and winters, and moist summers and autumns. Principal forest species include Hingan larch (*Larix gmelimii*), birch (*Betula platyphylla*), spruce (*Picea koraiensis*) and aspen (*Populus davidiana*). After the 1987 fire, the total burned area was approximately $2.31 \times 10^5 \text{ hm}^2$, occupying 57.3% of the total area. In order to emphasize the influence of fire, a subset of the bureau was clipped, which included $1.2 \times 10^5 \text{ hm}^2$ in the middle of the Tuqiang forest bureau, with 87.5% of the total area burned out in 1987.

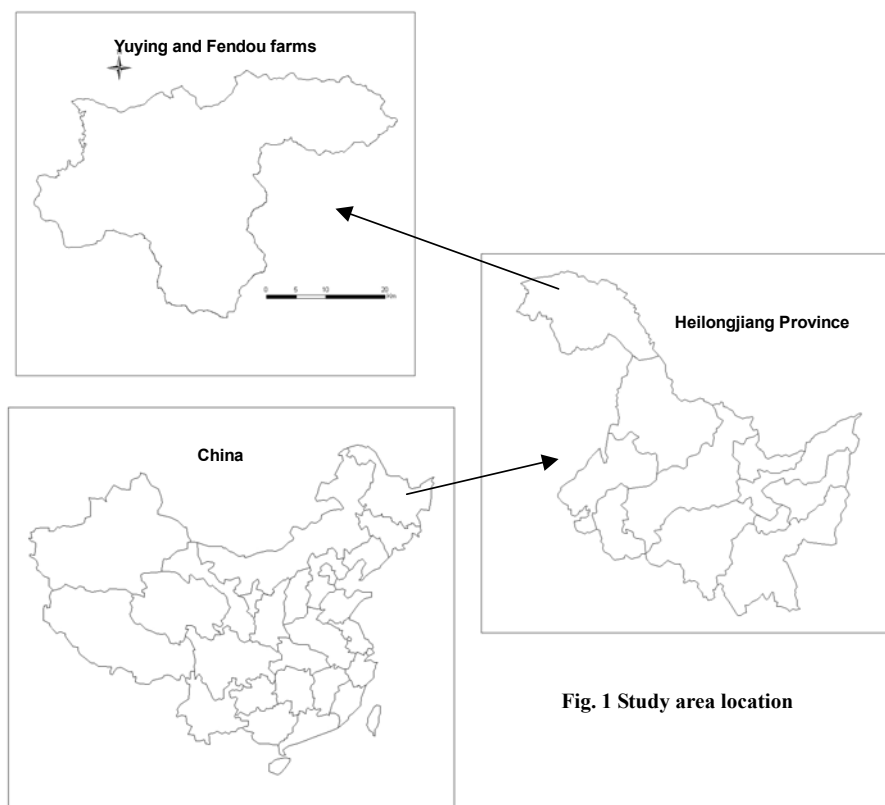


Fig. 1 Study area location

Suitable habitat map

First, factors related to suitable habitat were derived from existing field survey information in pertinent literatures (Zhang and Ma 1999), in which the habitat selection of sables was studied with radio-tracking and GPS during winter in the Great Xing'an Mountains. Four primary ecological factors were found to influence sables' selection: forest type, forest canopy density, forest age and slope position. However, slope position seemed to be in question, because different studies recorded divergent results of the effects of slope position on sables (Zhang and Ma 1999). In 2003, we conducted our own field survey, and consequently our results suggested that the reason why sables did not select valley and low slope position in the study of Zhang and Ma should be due to a proportionate lack of trees in the area studied, rather than due to slope position itself. We extracted forest type, forest coverage and forest age, while excluding slope position. A fuzzy evaluation method (Chen *et al.* 1999) was performed according to weightiness (Table 1), which could define values such that if one affecting factor grade is completely unsuitable for sables, the

value assigned will be 0. If the factors are determined to be most suitable, the value assigned will be 1. The values of moderately and marginally suitable were 0.67 and 0.33, respectively.

Second, forest stand maps of the burned area in pre-fire (1987) and post-fire (2000) stages were transformed into digital maps using ArcView 3.3 with related attribute data.

Third, the Ecological Niche Suitability Model (ENSM) was generated according to Shelford's Law of Tolerance (Odum 1971; OuYang *et al.* 1996). Shelford's Law states that for an organism to grow and reproduce in a given environment, any factors including ecological conditions which govern its growth should remain within the tolerance range of that organism; otherwise, the organism cannot exist. Therefore, ENSM was introduced to analyze the environmental features to map the suitable habitat of sables combined with GIS (ArcGIS) using digital forest stand

maps in this study. ENSM can be stated as
$$S_j = \prod_{i=1}^n S_i$$
 where S_j is the general suitability of landscape units, S_i is the

value of various ecological factors and n is the number of ecological factors ($n = 4$ in this study). If any value of the factors is 0, S_j is 0; S_j is 1 only if all four factors are optimal. Based on S_j , suitability of habitat can be classified into six grades (Chen *et al.*

1999) (Table 2). After filtering and excluding patches of less than 400 ha, which is the smallest nesting area for sables, final suitability grade maps were generated (Fig. 2 and Fig. 3).

Table 1. Suitable habitat factors value (from literatures)

Factors	Most suitable	Moderately suitable	Marginally suitable	Unsuitable
Forest type	Coniferous forest	mixed forest	Broad-leaved forest	Non-stacked forest
Forest age	≥ 100 a	80–100 a (including 80 a)	40–80 a	≤ 40 a
Coverage	0.40–0.60 (including 0.4 and 0.6)	0.60–0.8 or 0.30–0.40 (including 0.3)	0.10–0.30 (including 0.1)	< 0.10 or ≥ 0.80
Value	1	0.667	0.333	0

Table 2. Criterion of suitability grade

Suitability grade	unsuitable	Less suitable	marginally suitable	Moderately suitable	Suitable	Most suitable
Grade code	1	2	3	4	5	6
S_j	0	0.07, 0.04	0.22, 0.15, 0.11	0.45, 0.33, 0.30	0.67	1

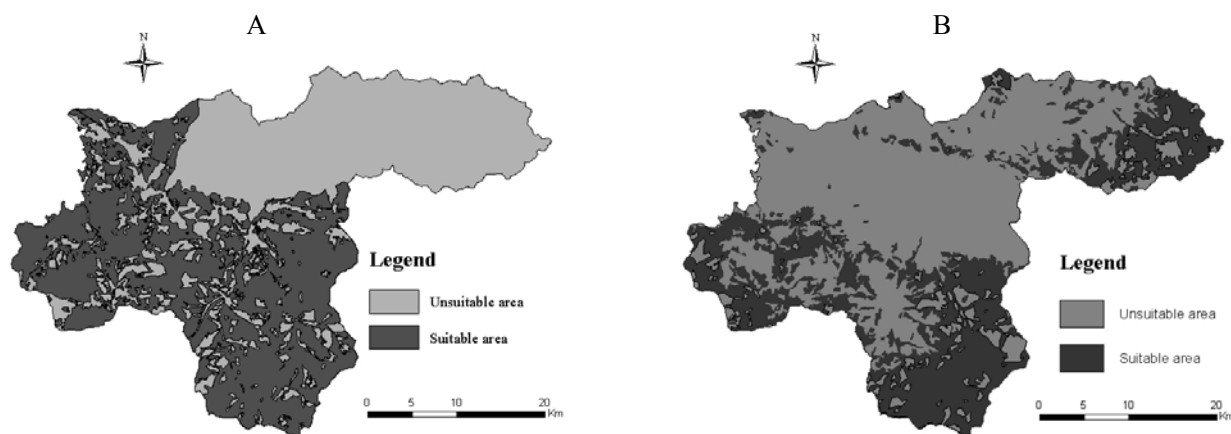


Fig. 2 Map of suitable habitat types for sables at coarse classification regime pre-fire and post-fire
A, pre-fire; B, post-fire

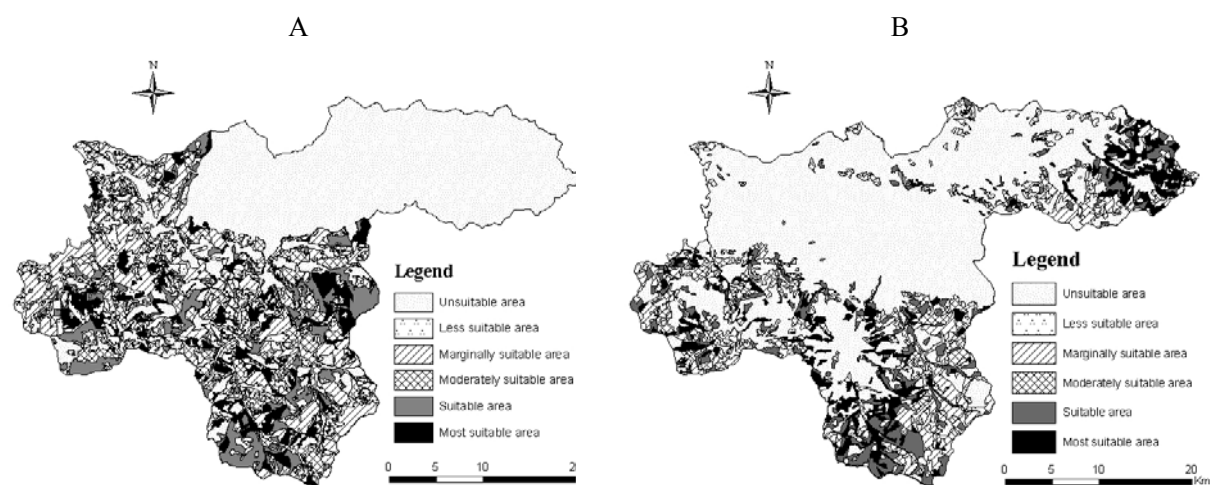


Fig. 3 Figure A Map of suitable habitat types for sables under fine classification regime pre-fire and post-fire
A, pre-fire; B, post-fire

In order to understand the structural changes of sables' habitat in the pre- and post-fire stages, studies involving two regimes were conducted. One regime was finer, including six suitability grades of habitat (Table 2), and the other was coarser, at which habitat was only sorted into suitable habitat types of most suitable, suitable, moderately suitable, marginally suitable and unsuitable area (including both less suitable and unsuitable area). Here, most suitable area was designated as at least three ecological factors ranked at most suitable. Suitable area denotes two factors ranked most suitable and one ranked secondly suitable. Moderately suitable areas included three states: one most suitable factor and two secondly suitable factors, two most suitable factors and one less suitable factor, or three secondly suitable factors. Marginally suitable areas also include three states: one most suitable factor, one secondly suitable factor and one less suitable factor; two secondly suitable factors and one less suitable factor; or one most suitable factor and two less suitable factors. Less suitable areas included two states: one secondly suitable factor and two less suitable factors, or three less suitable factors. Unsuitable area included at least one unsuitable factor.

Next, landscape indices that can reveal the habitat pattern were calculated for each of the two classification schemes respectively, based on digital suitability grade maps (Gustafson and Parker 1994; Schumaker 1996; Chen *et al.* 2002; Li *et al.* 2004) (Table 3). These indices included: Total Area (TA), showing suitable habitat loss; Number of Patches (NP), Patch Density (PD) and Splitting Index (SPLIT), accounting for habitat patch attributes and fragmentation; Aggregation Index (AI), explaining the contagion of the suitable patches; and Perimeter-Area Ratio (PARA), revealing the shape of patches for habitat types. The differences of habitat pattern between pre-fire and post-fire on two scales were described, which can be expressed as follows:
Change (%) = (index value pre-fire – index value post-fire) / index value pre-fire × 100%

Table 4. Criterion of boundary type

	Most suitable	Suitable	Moderately suitable	Marginally suitable	Less suitable	Unsuitable
Most suitable	Soft	Soft	Hard	Hard	Hard	Hard
Suitable		Soft	Soft	Hard	Hard	Hard
Moderately suitable			Soft	Soft	Hard	Hard
Marginally suitable				Soft	Hard	Hard
Less suitable					Hard	Hard
Unsuitable						Hard

Habitat structural change pre- and post-fire under the coarse classification regime

Table 5 illustrated landscape indices reflecting the change of habitat pattern for pre-fire (1987) and post-fire (2000) stages in the coarse classification regime for the study area. The suitable area was reduced by 15 783 hm², or 28 %, in the post-fire stage compared with the pre-fire, while the unsuitable area was increased by 25%, indicating that suitable habitat had decreased remarkably, despite adoption of many forest restoration measures. SPLIT in the suitable area increased by 214%, which indicated that suitable area had undergone severe fragmentation in the post-fire stage; however, in the unsuitable area, SPLIT decreased by 48%. AI in the suitable area decreased by 0.53%, while that in the unsuitable area increased by 0.54%, which indicated that

Table 3. Description of metrics used to quantify landscape structure (McGarigal and Cushman 2002)

Indices	Description	Units
TA	Total area of the same habitat type	Hectare
SPLIT	Total landscape area squared, divided by the sum of habitat type area	None
AI	The number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100	None
PARA-MN	Ratio of the patch perimeter (m) to area (m ²).	None

Boundary contrast could be an important factor for boundary permeability. It referred to the degree to which habitat types on either side of the boundary differ from one another, and may be described as abrupt, sharp, and hard (Forman 1995), or as soft and gradual (Desrochers *et al.* 2003). In this study, according to the contrast of the habitat suitability types, hard edges and soft edges were sorted (Table 4). Because of the low patch contrast on each side, the soft boundary was relatively simple for sables to migrate, while a hard boundary presented relative difficulty. The Percentage of Edge Contrast Type (PECT) was introduced to analyze the change in constitution of different boundary contrast types in pre- and post- fire stages, which can be expressed as follows:

$$PECT = \frac{\sum_{i,j=1}^m L_{ij}}{L_t}$$

where L_{ij} is the length of edge between two adjacent habitat types i and j , and L_t is the total landscape edge length. In this representation, map boundary was not accounted for either L_{ij} or L_t .

while isolation of the suitable patches had increased, that of the unsuitable patches had aggregated. The PARA-MN in unsuitable and suitable areas decreased by 1.4% and 9.6%, respectively, which suggested that patch shape tend to become simple within the entire study area.

Table 5. Landscape indices of sables' habitat under coarse classification regime

Indices	Pre-fire (1987)		Post-fire (2000)		Change (%)	
	S	U	S	U	S	U
TA	56947	63289	41164	79072	-28	25
SPLIT	10.1	5.59	31.75	2.88	214	-48
AI	97.61	97.87	97.09	98.40	-0.53	0.54
PARA-MN	200.8	204.6	197.9	185.0	-1.4	-9.6

Note: S--- Suitable Area; U—Unsuitable area

Habitat structural change pre- and post-fire under fine classification regime

All indices of suitability grades had changed after fire in the fine classification regime (Fig. 4). TA in unsuitable areas increased by 25% in 2000, which indicated that the unsuitable area expanded remarkably. TA reduced for all suitability types except most suitable, especially those within less, marginally, and moderately suitable areas (67%, 46% and 34%, respectively), while TA in most suitable areas increased by 13% (Fig. 4A). SPLIT in all suitable types was greater than that in unsuitable areas in both 2000 and 1987, and SPLIT increased remarkably in all suitable types except most suitable areas (Fig. 4B). Among all the suitable types, SPLIT within less suitable types changed most remarkably, increasing by 366%. But SPLIT within unsuitable and most suitable areas decreased by 48% and 60%, respectively,

which showed that fragmentation for all suitable types but most suitable had aggravated significantly in the post-fire stage. AI in all suitable and unsuitable types changed only slightly (Fig. 4C). AI in unsuitable and less suitable areas increased by 0.61% and 0.33%, while that in other suitable areas decreased, which indicated that isolation of suitable grade patches had aggravated, especially that of suitable and most suitable habitats, while the unsuitable and less suitable areas had aggregated. PARA-MN in unsuitable, moderately suitable and suitable areas decreased by 6.9 %, 4.1% and 6.5%, respectively, but less suitable, marginally suitable and most suitable areas increased by 16.9 %, 19.6 % and 0.7 %, respectively (Fig. 4D). Unlike hard boundaries, soft boundaries decreased by 1.1%, which indicated that while those boundaries that can impede the movement of sables increased, the change was not great (Fig. 4E).

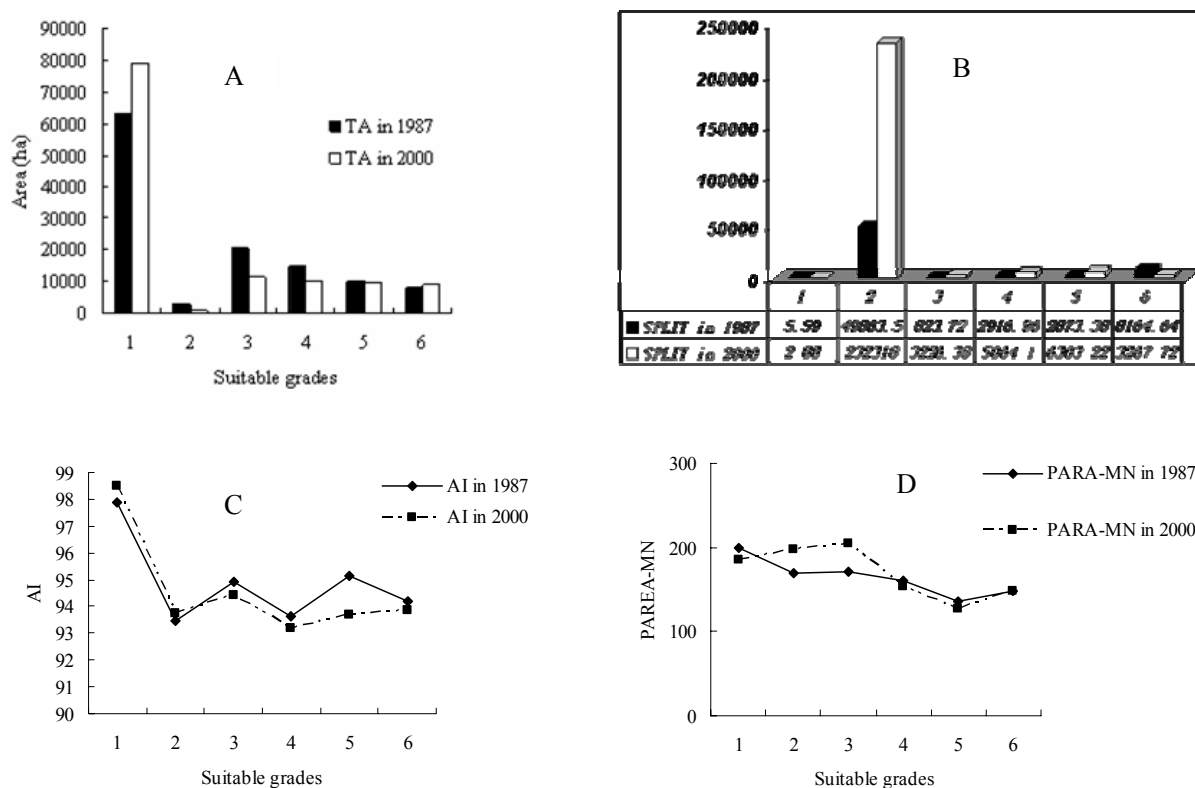


Fig. 4 Change of landscape indices of suitability grades pre- and post-fire under fine classification regime

A, change of TA; B, change of SPLIT; C, change of AI; D, change of PARA-MN; E, change of PECT
1--unsuitable; 2--less suitable; 3-- marginally suitable; 4-- moderately suitable; 5--suitable; 6-- most suitable

Discussion

Habitat loss

If the area percentage of suitable habitat in the landscape was less than the threshold value of 30%-50% at the landscape scale, the persistence of many species could not be assured (Flather and Bevers 2002). Although there was considerable divergence on this threshold value range for different animals (Andrén 1994), the confirmation of a great deal of research indicated that this range remained a useful reference (Lande 1988; Gibbs 1998;

Jansson and Angelstam 1999). In this study, the suitable area decreased from 47% in the pre-fire stage to 34% in the post-fire stage under the coarse classification regime, meaning that sables were near the critical threshold in this area after the fire. Long-term harvest and the expansion of residential areas were primary factors that induced habitat loss during the pre-fire stage, and the catastrophic fire aggravated this loss. With respect to the AI under the fine classification regime, the proportion of suitable areas changed only indistinctly, while the proportion of most suitable areas increased. This may be due to the practice of promoted regeneration measures instead of harvesting in the

post-fire stage, and because those trees surviving the fire were reserved and developed to the degree found in suitable and most suitable areas. Unsuitable areas increased from 53% pre-fire to 66% post-fire. Considering the severity of the 1987 fire and the immense area involved, a great number of trees were burned out, which resulted in the decrease of less suitable, marginally suitable and moderately suitable areas, while unsuitable areas increased.

The results given above indicated that suitable habitat loss was severe, though measures of afforestation were adopted post-fire. The key ecological factor providing food and environmental cover for sables was vegetation, especially forest. Therefore, the post-fire restoration of sable habitat should rest primarily upon forest landscape restoration. Considering the slow growth of conifers, the time required to restore the suitable habitat would be substantial. In addition, marginally and moderately suitable habitats as dominant grades with large areas of loss can influence further restoration of the habitat quality.

Habitat fragmentation

SPLIT in unsuitable areas decreased notably. In the meantime, AI increased in 2000, in both the coarse and fine classification regimes, which indicated that unsuitable patches became more continuous and clumpy. The changes in SPLIT and AI in suitable areas under the coarse classification regime showed that fragmentation and isolation aggravated in the suitable areas. However, changes in SPLIT and AI for various suitable types under the fine classification regime were somewhat different. The changes in SPLIT and AI within marginally suitable, moderately suitable and suitable areas were the same as that found in suitable areas under the coarse classification regime. Considering that the total area of these three types occupied 80% and 75% in 1987 and 2000, respectively (Fig. 2A), changes of marginally suitable, moderately suitable and suitable types were the principal trend within the whole suitable area. Changes in SPLIT and AI in less suitable areas were nearly opposite those found within most suitable areas. The results for the former revealed that less suitable patches not only became fragmented, but also tended to be isolated. Combined with the extensive decrease of area in this type, less suitable area may vanish and convert to unsuitable area as a result of the catastrophic fire. The latter indicated that conditions in most suitable areas ameliorated considerably, with these areas benefiting significantly from protective measures introduced to the surviving trees. In general, suitable area became more fragmented, and suitable patches were isolated from one another after the catastrophic fire.

Edge effect

In this study area, due to the influence of fire upon the habitat, sables were restricted within the unburned or lightly burned mosaics. The redistribution would rely mainly on the migration of sables. Stamps, *et al.* (1987) suggested that boundary shape and permeability would interact to determine an animal's migratory pattern. They defined boundary permeability as the tendency of an animal to cross over a boundary when it is encountered (Stamps *et al.* 1987). In this study, it was evident that soft boundaries were more permeable than hard edges. The change in soft boundary type was diminutive, with the percentage decreasing from 34.3% to 33.3%. The change in hard boundaries increased, which revealed that change of boundary type after fire may exert a negative influence on sable's movement, though the influence was slight. On the other hand, as the PARA-MN increased, emigration increased as well (OuYang *et al.* 1996; Ka-reiva 1985; Wen and Zheng 1996). PARA-MN in suitable areas

decreased under the coarse classified regime, indicating that emigration of sables was more difficult in the post-fire stage. Change of PARA-MN under the fine classified regime further confirmed the conclusion above. Changes in less suitable and marginally suitable areas were conducive to emigration, while those in moderately suitable and suitable areas promoted immigration, which could result in excess concentration of sables within suitable areas and impede their redistribution across the landscape in the post-fire stage. The results above demonstrated that shape and PECT exerted a negative influence on the migration of sables. However, Collinge and Palmer (2002) observed that the final edge effects depended on the interactive effects of two patch characteristics (Collinge and Palmer 2002), shape and boundary contrast, and the responses of different animals to similar landscape conditions. Due to a present lack of knowledge on sables' responses to the interaction of changed patch shape and boundary contrast, a more complete picture of edge effects for sables remains unclear. Further study in this respect remains to be done to understand their behavior in post-fire situations.

Taylor *et al.* (1993) pointed out that the degree of isolation should be a combination of the dispersal abilities of the animal and the constitution of the matrix (Taylor *et al.* 1993). Therefore, in addition to the changes of habitat attributes, the dispersal abilities of sables that were often related to the ecological and behavioral attributes also played an important role in the post-fire distribution pattern of sables. But again, how sables would respond to the changed habitat after fire is unknown, and remains to be observed.

Conclusion

Though forest cover had mostly restored in 2000, compared to the pre-fire situation, the area of suitable habitat in winter reduced greatly, especially that of the moderately suitable habitat. Fragmentation in most suitable areas was aggravated, with suitable patches more isolated in the post-fire situation. Unsuitable habitat became the landscape matrix, with interspersions in the suitable habitat mosaic. The situation of less suitable area deteriorated noticeably, while that of the most suitable area improved significantly. Changes in edge effects after fire could impede migration of sables, and further influence the redistribution of sables after fire. In general, most of the suitable area had deteriorated, which would severely influence the sables subsistence and redistribution. Long-term observation and study for determining the responses of sables to the changed habitat remains to be done.

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